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# EFFECTS OF DWARF MISTLETOE ON GROWTH AND MORTALITY OF DOUGLAS-FIR IN THE SOUTHWEST

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ABSTRACT.—The effects of dwarf mistletoe (*Arceuthobium douglasii*) on growth and mortality of Douglas-fir (*Pseudotsuga menziesii*) were studied on 387 plots in mixed-conifer stands in three national forests in New Mexico and two in Arizona. Analyses of 8,570 trees showed that low infection ratings (dwarf mistletoe classes 1 or 2) had no significant effect on tree growth, but that losses increased markedly as infection severity increased. Average volume growth losses for trees over 10 inches in diameter were: dwarf mistletoe class 3, 10%; class 4, 25%; class 5, 45%; and class 6, 65%. Mortality of Douglas-fir in stands severely infested with dwarf mistletoe was three to four times that of healthy stands. These high losses confirm the need for silvicultural control of Douglas-fir dwarf mistletoe in the Southwest.

Dwarf mistletoes (*Arceuthobium* spp.) are the most serious disease agents in southwestern forests. They increase mortality, reduce growth of infected trees, reduce seed crops, and predispose infected trees to attack by insects and other pathogens (Hawksworth and Wiens 1972). Douglas-fir dwarf mistletoe (*A. douglasii* Engelm.) is common on Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *glauca* [Beissner] Franco), the most abundant and commercially valuable conifer species in southwestern mixed-conifer forests (Jones 1974). However, few quantitative data are available on the effects of this parasite on Douglas-fir in the Southwest, and current control guidelines are based primarily on research from other regions (Graham 1961, Jones 1974, Gottfried and Embry 1977).

Hawksworth and Lusher (1956) reported that on the Mescalero Apache Reservation in southern New Mexico mortality in mistletoe-infested Douglas-fir stands was almost four times that of healthy stands. In a survey of commercial forest lands in Arizona and New Mexico, Andrews and Daniels (1960) reported that the mortality rate in mistletoe-infested Douglas-fir stands was four times greater than in noninfested stands; they estimated annual mortality losses from Douglas-fir dwarf mistletoe to be between 20 and 27 million board feet. They also reported that losses due to mortality caused by the mistletoe are heavier in cutover than in virgin stands of Douglas-fir.

In ponderosa pine (*Pinus ponderosa* Laws.) volume losses from reduced growth in stands severely infested with southwestern dwarf mistletoe (*A. vaginatum* subsp. *cryptopodum* [Engelm.] Hawksw. & Wiens) have been shown to exceed mortality losses (Pearson 1950, Hawksworth 1961). Volume growth losses in mistletoe-infested Douglas-fir stands have not been quantified in the Southwest, but studies in other regions (Pierce 1960, USDA Forest Service 1962, Shea 1963, Haglund and Dooling 1972, Dooling et al. 1986, Filip and Parks 1987) have demonstrated substantial decreases in growth of severely infected Douglas-fir.

Before detailed management guidelines for Douglas-fir dwarf mistletoe control in southwestern mixed-conifer forests can be developed, information on the damage caused by the parasite is needed. Therefore, this study was initiated to provide quantitative data on growth and mortality losses associated with dwarf mistletoe on Douglas-fir in the Southwest.

## METHODS

In 1979, 150 rectangular, 0.2-acre plots[3] were placed in 60 stands in the Apache-Sitgreaves National Forest, Arizona (2–4 plots

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[3]Because measurements of length, area, and volume are traditionally expressed in English units in forestry, we have adopted that system here.

per stand). Dwarf mistletoe infection varied from "none" to "heavy." For each plot we recorded location, elevation, aspect, slope (to nearest 5%), slope position (upper one-sixth, intermediate two-thirds, or lower one-sixth), stand history, date disturbed (when applicable), and habitat type (Moir and Ludwig 1979). Plots were not located in stands that had been substantially disturbed in the last 12 years.

The following data were recorded for each tree greater than 4.5 feet in height:

1. Diameter at breast height (dbh) of Douglas-fir (nearest inch) and all other species (nearest 2.0 inches).

2. Height (nearest foot) and age of up to four Douglas-fir from each one-inch diameter class represented in the plot. Height (nearest 5.0 feet) for all other species in the plot.

3. Dwarf mistletoe rating (DMR, Hawksworth 1977) for all live trees and recently dead trees that could be assigned an accurate rating.[4]

4. Condition—alive or dead.

5. Radial growth (nearest 0.05 inch) at breast height for the last 10 years for three Douglas-fir from each DMR class and age class represented in the plot.

6. Height and breast height age of four to six dominant or co-dominant Douglas-fir with DMRs less than 3 and showing no signs of past suppression on increment cores for determination of Douglas-fir site index (Edminster and Jump 1976). Site index trees were selected outside the plot when necessary but were in the same stand and habitat type.

During 1980 and 1981, 237 rectangular plots were established in 40 stands (2–4 plots per stand) on the following national forests: Apache-Sitgreaves (98 plots) and Kaibab (12 plots) in Arizona, and Lincoln (57 plots), Carson (43 plots), and Santa Fe (27 plots) in New Mexico. Data-collection procedures were similar to those used in 1979 but were altered slightly to obtain data for the development of a yield-simulation model for southwestern mixed-conifer forests (Edminster and Hawksworth 1984, Edminster et al. 1990). Plots were selected using the same criteria as in 1979 except that plot size was adjusted to include at least 150 live trees greater than 4.5 feet in height. Stand data recorded for each plot were the same as in 1979. The following data were recorded for each tree greater than 4.5 feet in height in a plot: species, dbh (nearest 0.1 inch), DMR, crown class (dominant, co-dominant, intermediate, suppressed), mortality rating (dead 0–5 years, dead 6–10 years, dead over 10 years), and 10-year radial growth (nearest 0.05 inch) at breast height for trees greater than 0.5 inch dbh. In addition, height and age data were taken for the following trees: total height (nearest foot) of two or three living or dead trees from each one-inch diameter class represented for each species occurring in a plot, height (nearest foot) to base of live crown on live trees measured for total height, distance (nearest foot) from the ground to the fifth and tenth whorls from the top of the tree of live trees measured for total height, and breast height age for two live trees from each two-inch diameter class represented for each species in a plot. Selection of Douglas-fir site index trees followed the same criteria as in 1979. A total of 8,570 Douglas-fir were measured for growth during this study.

## RESULTS

Nearly two-thirds of the plots (249) had more than half their total plot basal area in Douglas-fir. About one-quarter of the plots (105) had no dwarf mistletoe, and an additional one-quarter (105 plots) were lightly infested (stand DMR 0.1–1.0). The remaining plots were distributed by stand DMR as follows: 1.1–2.0, 49 plots; 2.1–3.0, 58 plots; 3.1–4.0, 49 plots; and greater than 4.0, 21 plots. One hundred seventy-four (45%) of the plots were in virgin stands and the rest in cutover areas. The distribution by time since last cutting was 12–20 years (66 plots), 21–30 years (81 plots), and more than 30 years (66 plots). Total basal area ranged from 17 to 470 square feet per acre. Douglas-fir site index ranged from 46 to 110 feet at 100 years (dbh age).

[4]The 6-class dwarf mistletoe rating system divides the live crown of a tree into thirds, and each third is rated separately. 0 no mistletoe infection, 1 light infection, 2 heavy infection. In pines, the separation of each third into light or heavy categories is based on the percentage of branches infected (1 less than half the branches infected, 2 more than half infected). However, in Douglas-fir, because of the very small mistletoe plants and the frequent development of witches' brooms, a distinction based on a proportion of the crown volume affected by witches' brooms is more practical. Thus, if brooms occupy less than half the crown volume in a third, it is rated as 1, or 2 if more than half is occupied. The ratings for each third are totaled to obtain a dwarf mistletoe rating (DMR) for the tree. Adding the DMRs for all live trees in a stand and dividing the total by the number of trees equals the stand DMR.

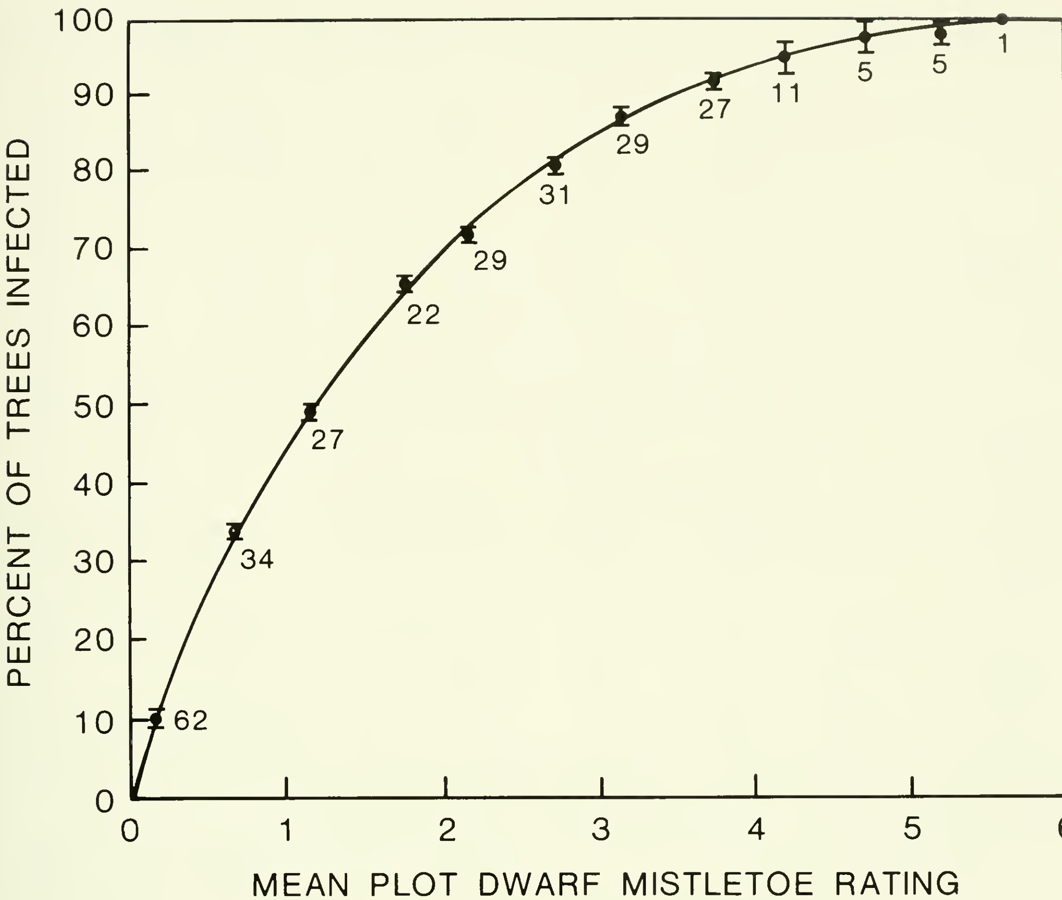


Fig. 1. Percent infection in relation to stand DMR for Douglas-fir dwarf mistletoe in southwestern mixed-conifer stands. The figures represent the number of plots in each 0.5 infection class.

TABLE 1. Ten-year radial growth for Douglas-fir by dwarf mistletoe rating (DMR) and diameter classes, and percent difference from DMR class 0.[a]

| | DMR 0 | | DMR 1 | | DMR 2 | | DMR 3 | | DMR 4 | | DMR 5 | | DMR 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diameter class (inches) | No. trees | Growth (inches) | No. trees | % Diff. | No. trees | % Diff. | No. trees | % Diff. | No. trees | % Diff. | No. trees | % Diff. | No. trees | % Diff. |
| 6.1–10.0 | 1,612 | 0.32 | 262 | +6 | 220 | +6 | 271 | −3 | 185 | −28 | 204 | −44 | 351 | −53 |
| 10.1–16.0 | 1,458 | 0.40 | 269 | −2 | 194 | −5 | 276 | −12 | 207 | −35 | 272 | −53 | 298 | −65 |
| 16.1–30.00 | 1,009 | 0.42 | 268 | 0 | 216 | 0 | 307 | −19 | 283 | −33 | 262 | −52 | 146 | −69 |
| All trees | 4,079 | 0.37 | 799 | +3 | 630 | +3 | 854 | −9 | 675 | −30 | 738 | −49 | 795 | −62 |

[a]Includes 1979–81 data.

The relationship between percentage of trees infected and stand DMR is shown in Figure 1. No significant differences in this relationship for trees in various diameter classes could be demonstrated.

Ten-year periodic radial growth at breast height was calculated for pole-size trees (dbh 6.1–10.0 inches), small sawtimber (dbh 10.1–16.0 inches), and large sawtimber (dbh > 16.0 inches) (Table 1). Little if any effect of dwarf mistletoe was found in DMR classes 1 or 2; overall, the percent reduction was about

TABLE 2. Ten-year periodic annual volume increment (PAI) by dwarf mistletoe rating (DMR) and diameter class for Douglas-fir (1980 and 1981 data only).

| | | Diameter class (inches) | | |
|---|---|---|---|---|
| | | Poles (6.1–10.0) | Small sawtimber (10.1–16.0) | Large sawtimber (16.0+) |
| DMR 0 | PAI[a] | 0.11A[b] | 0.35A | 0.84A |
| | N | 1,391 | 1,148 | 699 |
| DMR 1 | PAI | 0.12A | 0.34A | 0.83A |
| | N[c] | 166 | 173 | 134 |
| % change | | +9 | −3 | −1 |
| DMR 2 | PAI | 0.12A | 0.32A | 0.81A |
| | N | 143 | 110 | 109 |
| % change | | +9 | −9 | −4 |
| DMR 3 | PAI | 0.10A | 0.33A | 0.75B |
| | N | 197 | 172 | 167 |
| % change | | −9 | −6 | −11 |
| DMR 4 | PAI | 0.08B | 0.24B | 0.67B |
| | N | 141 | 139 | 122 |
| % change | | −27 | −31 | −20 |
| DMR 5 | PAI | 0.07B | 0.18C | 0.45C |
| | N | 148 | 192 | 140 |
| % change | | −36 | −49 | −46 |
| DMR 6 | PAI | 0.05C | 0.13D | 0.28D |
| | N | 296 | 229 | 105 |
| % change | | −55 | −63 | −67 |

[a]Ten-year periodic annual increment (cubic feet/year); trees larger than 6.0 inches dbh only.
[b]Numbers followed by different letters are significantly different within each diameter class, oneway ANOVA, $p = .05$, Student-Newman-Kuels.
[c]Percent change from DMR 0 (PAI).

10% for DMR class 3, 30% for class 4, 50% for class 5, and 60% for class 6.

Ten-year periodic annual (cubic) volume increment (Hann and Bare 1978) was determined by DMR class for pole-size trees (diameter ranges as above), small sawtimber, and large sawtimber size classes (Table 2). Percent change in 10-year periodic annual volume increment shows a pattern similar to that for 10-year periodic radial growth. Much variation was encountered for all size classes in DMR classes 1 and 2 but much less in classes 3–6. Class 3, 4, 5, and 6 trees had decreases in periodic annual volume of 6–11%, 20–31%, 36–49%, and 55–67%, respectively, when compared with the growth of healthy trees of the same size classes (Table 2). However, when a one-way analysis of variance ($p = .05$, Student-Newman-Kuels) was applied to the results, only large sawtimber-size trees with DMR greater than 2 and trees with DMR greater than 3 for the smaller size classes had statistically significant volume growth reductions when compared with the growth of healthy trees (Table 2). Percent reductions in 10-year periodic annual volume increment for all sawtimber-size trees averaged approximately 10%, 25%, 45%, and 65% for infection classes 3, 4, 5, and 6, respectively.

Although site index affected the rate of 10-year periodic annual volume increment (lower sites had lower growth rates), the reductions in volume increment associated with dwarf mistletoe infection followed the same pattern as above regardless of the site index class considered. Consistent differences in the growth loss patterns associated with dwarf mistletoe infection have been demonstrated for different habitat types using the data collected in this study (Mathiasen and Blake 1984). However, no differences in growth loss could be associated with other stand attributes such as slope, aspect, or elevation based on these data.

TABLE 3. Total cubic foot volume, infected live volume, and dead volume for Douglas-fir by stand dwarf mistletoe rating (DMR) class (1980 and 1981 data only).

| Stand DMR class | Number of plots | Total cubic feet/acre | Percent of live volume infected | Percent volume dead |
|---|---|---|---|---|
| 0 | 105 | 5,590 | 0 | 1.3 |
| 0.1–0.5 | 68 | 9,130 | 23 | 2.5 |
| 0.6–1.0 | 37 | 6,630 | 56 | 2.6 |
| 1.1–1.5 | 20 | 9,060 | 61 | 2.6 |
| 1.6–2.0 | 29 | 6,660 | 80 | 3.4 |
| 2.1–2.5 | 26 | 8,830 | 91 | 3.6 |
| 2.6–3.0 | 32 | 5,300 | 94 | 4.6 |
| 3.1–3.5 | 27 | 7,680 | 93 | 5.0 |
| 3.6–4.0 | 22 | 9,560 | 95 | 4.1 |
| >4.0 | 21 | 5,850 | 99 | 3.8 |

Total cubic volume, infected live volume, and dead volume were calculated for trees larger than 6.0 inches dbh by stand DMR classes (Table 3). The volume of dead trees doubled in plots with stand DMR of 0.1–1.5 and was two and one-half to almost four times greater in plots with stand DMR greater than 1.5 when compared with the percentage of dead volume in healthy plots.

Percent mortality was calculated for the following size classes: small saplings (dbh 0.1–1.0 inch), large saplings (dbh 1.1–6.0 inches), poles, small sawtimber, and large sawtimber (diameter ranges as above) by stand DMR classes (Table 4). Percent mortality ranged

TABLE 4. Percent mortality of Douglas-fir by stand dwarf mistletoe rating (DMR) and diameter class.

| Stand DMR class | Diameter class (inches) | | | | |
|---|---|---|---|---|---|
| | Seedlings (0.1–1.0) | Saplings (1.1–6.0) | Poles (6.1–10.0) | Small sawtimber (10.1–16.0) | Large sawtimber (16.0+) |
| 0 | 7 | 12 | 6 | 2 | 3 |
| 0.1–1.0 | 10 | 19 | 10 | 5 | 3 |
| 1.1–2.0 | 6 | 17 | 13 | 7 | 5 |
| 2.1–3.0 | 18 | 26 | 16 | 14 | 12 |
| 3.1–4.0 | 19 | 30 | 15 | 13 | 21 |
| 4.0+ | 24 | 44 | 35 | 22 | 16 |
| All plots | 10 | 20 | 12 | 8 | 6 |

TABLE 5. Percent mortality by stand history and diameter class for Douglas-fir.

| Stand history | Diameter class (inches) | | | | |
|---|---|---|---|---|---|
| | 0.1–1.0 | 1.1–6.0 | 6.1–10.0 | 10.1–16.0 | 16.0+ |
| Cutover (years) | | | | | |
| 12–20 | 5 | 17 | 15 | 9 | 4 |
| 21–30 | 5 | 19 | 9 | 4 | 3 |
| >30 | 15 | 18 | 10 | 6 | 10 |
| Virgin | 11 | 23 | 15 | 10 | 8 |

TABLE 6. Percentage of dead Douglas-fir with dwarf mistletoe ratings 0 and 2–6 by diameter class.[a]

| Diameter class (inches) | Total dead trees | Dwarf mistletoe rating | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0[b] | 2 | 3 | 4 | 5 | 6 |
| | | Percentage of dead Douglas-fir | | | | | |
| 0.1–1.0 | 443 | 70 | 4 | 4 | 7 | 3 | 12 |
| 1.1–5.0 | 1,238 | 68 | 3 | 3 | 6 | 5 | 15 |
| 5.1–10.0 | 354 | 58 | 1 | 2 | 6 | 12 | 21 |
| 10.1–16.0 | 227 | 49 | 1 | 1 | 9 | 14 | 26 |
| 16.0+ | 125 | 63 | 1 | 1 | 11 | 15 | 9 |
| Total | 2,387 | 65 | 3 | 3 | 7 | 7 | 15 |

[a]Does not include dwarf mistletoe ratings of 1 because this class included dead trees that could not be assigned an accurate rating. Trees with any indication of past mistletoe infection that could not be accurately rated were assigned a 1 to indicate they had been infected.
[b]May include infected old dead trees not having signs of past dwarf mistletoe infection. This category includes any mortality observed in plots that was probably not related to mistletoe infection.

from 1.3% to 5.0% but generally increased as stand DMR increased, particularly when the stand DMR was greater than 2.0. Mortality of small sawtimber demonstrated the largest increase in percent mortality as stand DMR increased (from 2% in healthy plots to 22% in plots with a stand DMR greater than 4.0). The percentage of dead trees was greatest for large saplings, compared with other size classes, in all stand DMR classes.

Mortality in most size classes was generally greatest in virgin stands compared to cutover stands (Table 5), but mortality in stands cutover more than 30 years prior to data collection was higher than in virgin stands for the small sapling and large sawtimber-size classes.

Forty-three percent of the dead Douglas-fir that could be accurately assigned a dwarf mistletoe rating were rated as class 6 (Table 6). Most infected dead trees in each size class were rated as class 6 except for the large sawtimber, where a higher percentage of dead Douglas-fir were rated as class 5. More dead trees in the small and large sapling-size classes were rated as class 4 than class 5. The percentage of dead Douglas-fir rated as classes 2 and 3 decreased as size class increased (Table 6).

## Discussion

The relationship between percentage of trees infected and stand DMR is similar to that reported for stands infected with lodgepole pine dwarf mistletoe (*A. americanum* Nutt. ex Engelm.) (Hawksworth 1978).

Severe dwarf mistletoe infection greatly reduces volume increment of Douglas-fir in the Southwest. Ten-year annual radial growth reductions for trees in DMR classes 3, 4, 5, and 6 averaged about 10%, 30%, 50%, and 60%, respectively. Statistically significant growth losses occur for sawtimber-size trees with infection levels greater than 3. Pierce (1960) in western Montana and Shea (1963) in Oregon also showed that growth rates of severely infected Douglas-fir were markedly reduced. In addition, Filip et al. (1990) found significant reductions in 10-year mean diameter increment in dwarf mistletoe–infested Douglas-fir stands in eastern Oregon and Washington. Wicker and Hawksworth (1988) gave general loss estimates for growth reduction for all dwarf mistletoes as about 10%, 25%, and 50% or more for trees in classes 4, 5, and 6, respectively. However, our results indicate that growth reductions for Douglas-fir in the Southwest are greater than these general estimates.

Our estimates of mortality in Douglas-fir dwarf mistletoe–infested stands are similar to those reported in the Southwest by Hawksworth and Lusher (1956) and Andrews and Daniels (1960). Although not tested statistically, mortality was generally higher in mistletoe-infested virgin stands than in cutover stands in this study. Hawksworth and Lusher (1956) reported similar findings for Douglas-fir stands in southern New Mexico, but Andrews and Daniels (1960) found higher mortality rates in cutover stands. Increases in mortality are generally related to increases in stand DMR. Mortality was highest for large saplings in each stand DMR class. The reasons for the higher mortality rate in the large sapling class are unknown, but they may be related to more severe competition for light, moisture, and nutrients, combined with increased stress related to mistletoe infection. Small saplings are subjected to severe competition, too, but usually have lower levels of mistletoe infection (Mathiasen 1986). The high mortality rates we observed in class 4 and 5 trees for Douglas-fir are in contrast to mortality patterns in mistletoe-infected ponderosa pines, where mortality is predominantly in class 6 trees (Hawksworth and Lusher 1956).

Douglas-fir dwarf mistletoe is widespread and common in southwestern mixed-conifer forests (Andrews and Daniels 1960, Hawksworth and Wiens 1972, Jones 1974, Gottfried and Embry 1977). This study demonstrates that the damage caused by Douglas-fir dwarf mistletoe in unmanaged forests can be significant in terms of increased mortality and reduced growth of Douglas-fir in heavily infested stands. Therefore, reducing population levels of this parasite through silvicultural management should be a high priority for resource managers in the Southwest.

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